.8/F

Publication 1029 April, 1958

STUDIES IN FOREST PATHOLOGY

XIX

Decay of Western Hemlock and Amabilis Fir in the Kitimat Region of British Columbia

R. E. Foster, J. E. Browne, and A. T. Foster

USP
CRAM
MH

Forest Biology Division
CANADA DEPARTMENT OF AGRICULTURE
OTTAWA, ONTARIO

COMMONWEALTH MYCOLOGICAL INSTITUTE
-8 JUL 1958

Studies in Forest Pathology

I. Decay in Balsam Fir (*Abies balsamea Mill.*). *By A. W. McCallum* - - 1928

II. The Biology of *Fomes pinicola* (SW.) Cooke. *By Irene Mounce* - - 1929

III. *Hypoxylon* Canker of Poplar. *By J. E. Bier* - - - - - - - - 1940

IV. Decay of Sitka Spruce on the Queen Charlotte Islands. *By J. E. Bier, R. E. Foster, and P. J. Salisbury* - - - - - - - - - - - - - 1946

V. Decay in Fir, *Abies lasiocarpa* and *A. amabilis*, in the Upper Fraser Region of British Columbia. *By J. E. Bier, P. J. Salisbury, and R. A. Waldie* - 1948

VI. Identification of Cultures of Wood-rotting Fungi. *By Mildred K. Nobles* 1948

VII. Decay in Western Hemlock and Fir in the Franklin River Area, British Columbia. *By D. C. Buckland, R. E. Foster, and V. J. Nordin* - - - 1949

VIII. Decay of Western Hemlock on the Queen Charlotte Islands, British Columbia. *By R. E. Foster and A. T. Foster* - - - - - - - - 1951

IX. *Fomes igniarius* Decay of Poplar. *By C. G. Riley* - - - - - - - 1952

X. Decay of White Pine in the Timagami Lake and Ottawa Valley Areas. *By L. T. White* - - - - - - - - - - - - - - - - - - 1953

XI. Decay in Black Cottonwood in the Middle Fraser Region, British Columbia. *By G. P. Thomas and D. G. Podmore* - - - - - - - 1953

XII. Decay of Western Hemlock in the Upper Columbia Region, British Columbia. *By R. E. Foster, H. M. Craig, and G. W. Wallis* - - - - - 1954

XIII. Decay in Sugar Maple in the Ottawa-Huron and Algoma Extension Forest Region of Ontario. *By Vidar J. Nordin* - - - - - - - - 1954

XIV. Decay of Douglas Fir in the Coastal Region of British Columbia. *By G. P. Thomas and R. W. Thomas* - - - - - - - - - - - - 1954

XV. Rootlets, Mycorrhiza, and Soil Temperatures in Relation to Birch Dieback. *By D. R. Redmond* - - - - - - - - - - - - - - - 1955

XVI. Decay of Balsam Fir, *Abies balsamea* (L.) Mill., in the Atlantic Provinces. *By A. G. Davidson* - - - - - - - - - - - - - - - - - - 1957

XVII. The Pathological Deterioration of Fire-Killed Pine in the Mississagi Region of Ontario. *By J. T. Basham* - - - - - - - - - - - 1958

XVIII. The Occurrence of the Indian Paint Fungus, *Echinodontium tinctorium* E. & E., in British Columbia. *By G. P. Thomas* - - - - - - - - 1958

Publication 1029 April, 1958

STUDIES IN FOREST PATHOLOGY

XIX

Decay of Western Hemlock and Amabilis Fir in the Kitimat Region of British Columbia

R. E. Foster, J. E. Browne, and A. T. Foster

Forest Biology Laboratory,
Victoria, B.C.

CANADA DEPARTMENT OF AGRICULTURE

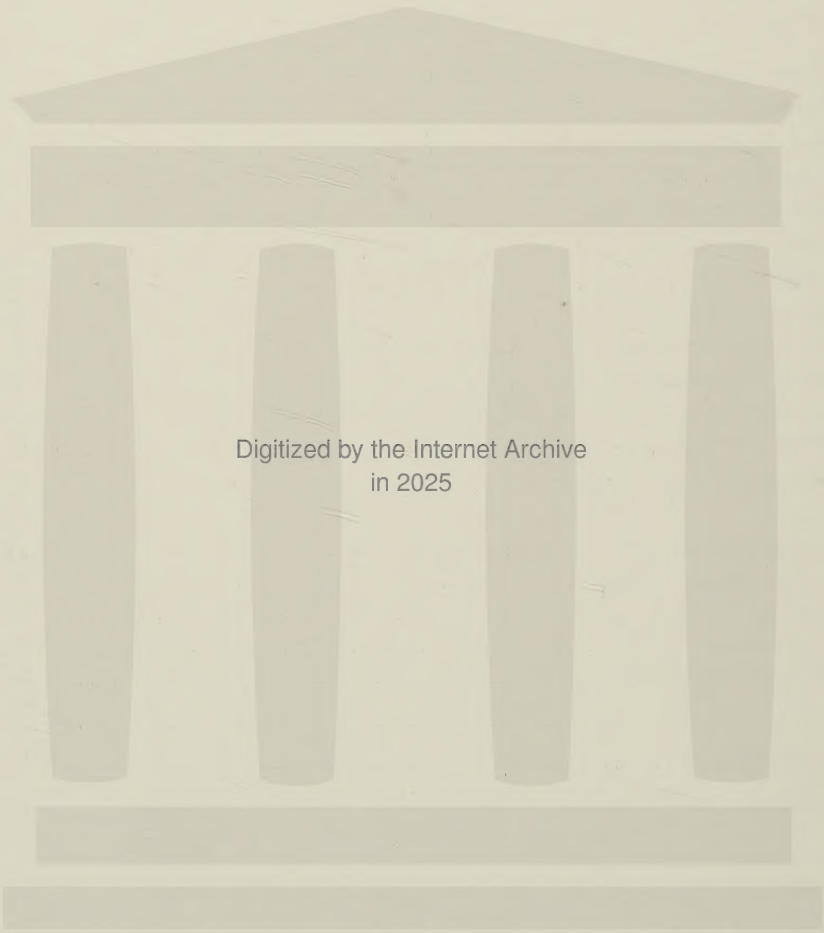
2M—23565—4:58

EDMOND CLOUTIER, C.M.G., O.A., D.S.P.
QUEEN'S PRINTER AND CONTROLLER OF STATIONERY
OTTAWA, 1958

Cat. No. A43-1029

CONTENTS

	Page
INTRODUCTION	5
REVIEW OF PREVIOUS INVESTIGATIONS	5
METHOD OF STUDY	6
Location of sample areas	6
Field procedure	7
Description of sample areas	8
DECAY OF AMABILIS FIR	10
Basic loss	10
Fungi responsible for decay	11
External indicators of decay	15
Diameter relationships	16
Age relationships	18
Correlation analyses	21
DECAY OF WESTERN HEMLOCK	23
Basic loss	23
Fungi responsible for decay	23
External indicators of decay	25
Diameter relationships	26
Age relationships	29
Correlation analyses	30
DISCUSSION	32
ACKNOWLEDGMENTS	35
REFERENCES	36



Digitized by the Internet Archive
in 2025

https://archive.org/details/publications-canada-department-agriculture_1958-04_1029

INTRODUCTION

Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and amabilis fir (*Abies amabilis* (Dougl.) Forbes)[1] in the Kitimat region of British Columbia have long been considered highly defective species of forest trees. Substantial cull factors have been applied to most of the mature forests in this region and in some cases have led to rejection of more than 50 per cent of the total volume per acre because of the known or assumed prevalence and severity of decay. This reported damage has created a problem of some concern when it comes to development of forest management policies and utilization of mature forests; thus it has emphasized the need for more precise information about the nature and extent of defect.

Detailed pathological investigations in the Kitimat region by the Forest Biology Laboratory from 1949 to 1951 were carried out in co-operation with the British Columbia Forest Service, the Powell River Company, and Columbia Cellulose Company Limited. Main objective of the studies was to evaluate the susceptibility to decay of mature hemlock and fir, and to provide a reliable method of estimating hidden defect in mature forests. This report constitutes a summary and interpretation of data derived from the analysis of 496 living hemlock and 424 living fir contained on 53 sample plots believed to be representative of the region.

REVIEW OF PREVIOUS INVESTIGATIONS

Very little information about the pathology of hemlock or fir in the Kitimat region was available prior to the beginning of the present study.

Mulholland in 1921 (17) was among the first to report on the condition of mature forests in this region. His survey, confined to the Lakelse River valley, indicated that 50 per cent of the hemlock was worthless and that from 10 to 20 per cent of the volume of remaining trees was defective. Although major attention in this study was directed to overmature and decadent forests, it was considered doubtful that younger trees were adding enough wood to equal annual loss from decay.

Clarke (8) surveyed hemlock-fir forests adjacent to the Wedeen and Kitimat Rivers south of Lakelse Lake in 1921 and reported that the majority of stands were overmature and decadent. Most trees over 36 inches d.b.h.[2] were culls[3] resulting from decay and the volume of wood from trees of smaller diameter was substantially reduced.

In 1922 Clarke (9) extended his survey to the Clearwater River valley east of Lakelse Lake. He reported hemlock to be of even poorer quality than at Kitimat; most trees over 30 inches d.b.h. were considered worthless. Loss factors applied to the remaining stand of fir and hemlock after cull trees were rejected averaged 17 and 25 per cent respectively.

---

[1]Will be referred to as hemlock and fir in following pages. Mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) is known to occur in this region but was not present in the specific areas selected for analysis.

[2]Diameter at breast height outside bark.

[3]An arbitrary standard of unmerchantability applied to western tree species. In normal practice a cull tree is defined as one in which more than 50 per cent of the gross volume is defective.

52292–0—2

An intensive pathological survey undertaken by Bier (3) in the Kitimat River valley north of Minette Bay in 1945 showed that forests in this area contained an overstory of old-growth trees of large diameter and substantial defect; the understory of younger, smaller, and less defective trees was in varying stages of suppression. Cull factors, calculated from a sample of 163 trees, were reported to be 40 per cent for hemlock and 20 per cent for fir. Little loss was encountered in trees less than 250 years of age but beyond this age defect was substantial. *Echinodontium tinctorium* Ell. & Ever. was of primary importance in hemlock, causing 60 per cent of the total loss from decay in this species; *Trametes pini* (Thore) Lloyd contributed 53 per cent of the total loss from decay in fir.

These studies, although providing information about the importance of decay in specific areas, were difficult to interpret more generally; they were considered to be much less valuable than more recent methods of inventory and management appraisal. The studies indicated, however, that important differences in the pathology of hemlock and fir could be expected, and that existing data gained elsewhere in British Columbia about these or closely related tree species (2, 5, 6, 13, 14, 19) did not apply to the Kitimat region.

METHOD OF STUDY

Location of Sample Areas

All field work took place in the southern half of the Kitimat Trench, a major topographic feature extending approximately 90 miles from the head of Douglas Channel through the Kitimat, Lakelse, and Kitsumgallum Watersheds to the Nass River (Figure 1). The Trench is in the form of a broad, largely drift-filled valley intersected at Terrace by the Skeena River and by low divides separating the three major watersheds. Adjacent slopes of the Coast Mountains extend from 2,000 to 6,000 feet above sea level. The region is characterized by cool, relatively dry summers and by mild, wet winters. The average annual precipitation is variable, ranging from 94 inches on Douglas Channel to 46 inches on the Skeena and Nass Rivers. Further variation results from a rain-shadow influence north of Kitsumgallum Lake where rainfall averages approximately 33 inches a year (18). Mean monthly temperatures at Terrace, centrally located in the Kitimat Trench, range from 25°F. in January to 62°F. in July and August. Soils for the most part are of glacial or alluvial origin and of the brown podzolic group (11). The major forest species within the region are western hemlock and amabilis fir. Sitka spruce (*Picea sitchensis* (Bong. Carr.) and western red cedar (*Thuja plicata* Donn) occur in association on favorable sites and lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) may occur as a pioneer species following fire. Mountain hemlock is present in some areas, particularly at higher elevations.

Field studies were carried out in the Lakelse and Kitsumgallum Watersheds and on the divide separating the Lakelse and Kitimat drainages. Specific sample areas were located on Lot 2678 southwest of Lakelse Lake in the vicinity of Andalas Creek, on Lots 2681 and 2684 southeast of Lakelse Lake in the vicinity of Onion and Clearwater Lakes, on Lot 477 south of Kitsumgallum Lake in the vicinity of Pine Lake, and adjacent to Lot 497 north of the Nelson River and adjacent to Kitsumgallum Lake. For convenience, these four sample areas appear in the following pages as Andalas Creek, Clearwater Lake, Pine Lake, and Kitsumgallum Lake.

Field Procedure

Eleven or more rectangular sample plots, each 0.25 acres in extent, were located by means of mechanical line-plot selection in each of the four sample areas. Plot boundaries were altered when it was necessary to avoid rock outcrops, large streams, and other topographic features; no changes resulted from indicated or assumed incidence of decay. The tally included all trees 5.6 inches d.b.h. and over and the following information was recorded: species, d.b.h., crown class, total height, and nature and location of visible abnormalities.

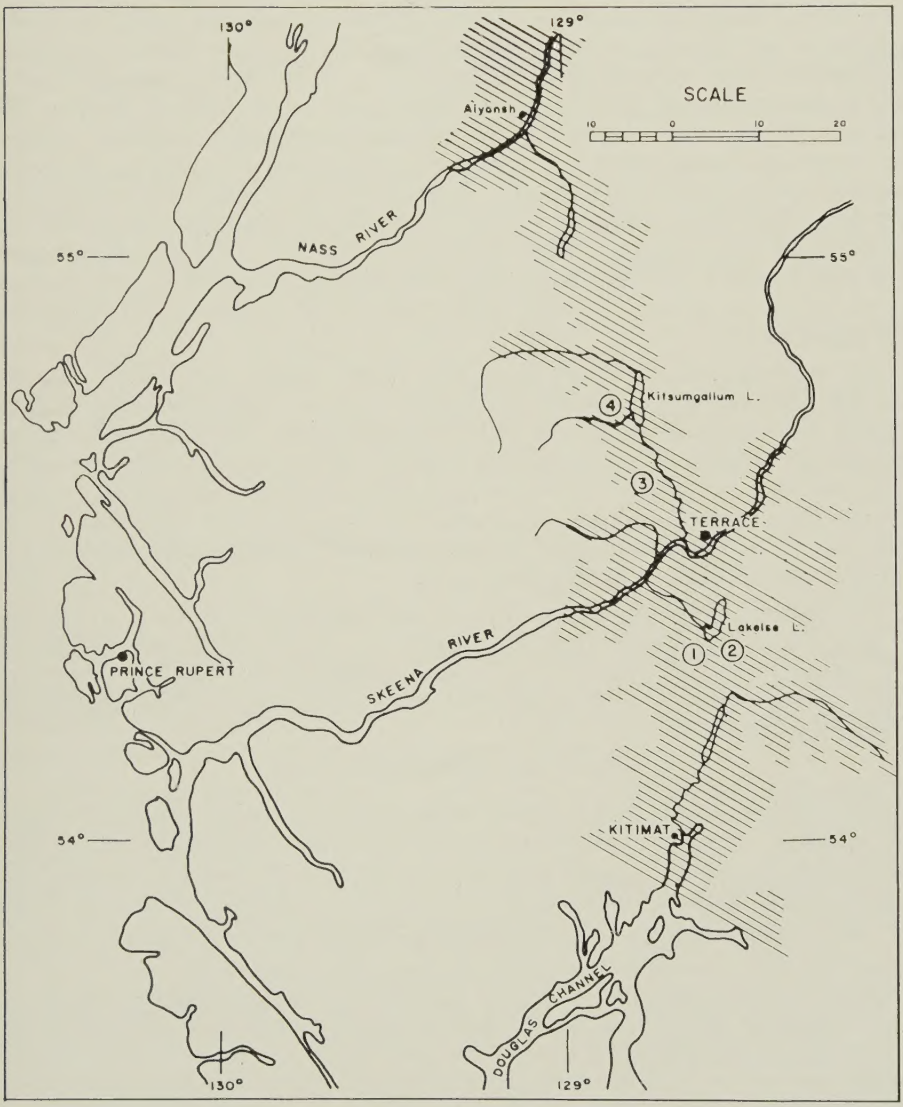


FIG. 1. Map of the Kitimat region, B.C. The shaded area encompasses the Kitimat Trench between sea level and 3000 ft. elevation. The circles represent the approximate locations of sample areas as follows: (1) Andalas Creek, (2) Clearwater Lake, (3) Pine Lake, (4) Kitsumgallum Lake.

52292-0—2½

Abnormalities were recorded with the thought that some of them might indicate internal defect and therefore permit more detailed analysis of the distribution of decay within and between stands. The plan for the study called for an analysis of each abnormality to determine the volume, if any, of associated defect. This proved in most cases to be impossible because of the frequent and adjacent association of multiple injuries and the difficulty of relating volumes of decay to specific avenues of entrance. A number of abnormalities, previously found to be significant in estimating decay in fir and hemlock in other regions, occurred too infrequently in the Kitimat region to warrant analysis. It was necessary to assume, therefore, that the specific abnormalities recorded elsewhere as signifying decay in mature coniferous stands (12) would apply to fir and hemlock in the present sample. Accordingly, living trees free from defined abnormalities were designated as Residual (R), while those possessing one or more abnormalities of predetermined significance were termed Suspect (S); dead trees (D) were included in the classification in a separate category. Suspect trees were further segregated into two classes, designated as S_1 and S_2; the former contained swollen knots (blind conks), large rotten branches, frost cracks, scars, dead or broken tops, forks, or trunk infections of mistletoe; the latter had one or more sporophores. This modification of the original classification was made because it was felt that it would be possible to measure more precisely the occurrence of decay in stands if the known and suspected defective trees were segregated.

All hemlock and fir larger than 14.5 inches d.b.h. were felled, cut into 4- to 8-ft. lengths, and examined critically for decay. Measurements of decay included incipient, advanced, and final stages; this total diameter of decay was increased by one inch before making volume calculations. Arbitrary culling standards were not used. Gross volume measurements were made at 16-ft. intervals from stump height to a top diameter inside bark of eight inches. No deductions in gross volume were made because of breakage; all volumes were computed on the basis of Smalian's formula.[4]

To determine the total ages of trees, the estimated number of years for a tree to grow to the measured stump height was added to the stump age. In cases where it was not possible to obtain a complete age count, ages were considered to be equal to those of adjacent trees of the same d.b.h., height, and increment pattern.

Description of Sample Areas

Description of each plot included slope, aspect, elevation, dominant vegetation, and soil characteristics but later were extended[5] and related to a forest classification based on a more complete recognition of floristic structure and ecosystem (21, 22). Two habitats, referred to in this study as the "Fern" and" Moss" associations, were sampled and described as follows:

Western hemlock—amabilis fir—beech fern—oak fern association

Characteristic vegetation: *Tsuga heterophylla, Abies amabilis, Dryopteris dilitata* (Hoffm.) A. Gray, *Dryopteris linnaeana* C. Chr., and *Mnium punctatum* Hedw.

---

[4] $V = \frac{(B + b)}{2} L$; V = volume, B = area of base, sq. ft., b = area of top, sq. ft., L = length, ft.

[5] The authors are indebted to Dr. G. P. Thomas, Forest Biology Laboratory, Victoria, B.C., for modification and extension of the original descriptions as indicated.

Topography: nearly flat to moderate slopes.

Soil: podzolized brown; of alluvial or glacial origin; deep mineral zone with either silty-sand or sand and gravel texture; granular to lightly compacted structure.

Water relations: entire profile continuously moist and seasonally wet.

Dominant tree growth: western hemlock occurs in all canopies with excellent vigor; attains best regional development on this association. Amabilis fir occurs in all canopies with good vigor; sometimes replaces hemlock as the major species.

Western hemlock—amabilis fir—tall blue bilberry—moss association

Characterictic vegetation: *Tsuga heterophylla, Abies amabilis, Vaccinium ovalifolium* J. E. Smith, *Hylocomium splendens* (Hedw.) Bruch. & Schimp., *Rhytidiadelphus loreus* (Hedw.) Warnst., and *Rhytidiopsis robusta* (Hook.) Broth.

Topography: flat to sloping with good surface drainage.

Soil: strongly podzolized brown; of alluvial or glacial origin; mineral zone of variable depth, 6 to 38 inches, with either silty-sand or sand and gravel loam texture; structure granular or aggregated near the surface, becoming either compacted or cemented below.

Water relations: sub-surface irrigation generally low during the summer and most of soil surface dry during this period.

Dominant tree growth: western hemlock occurs with good vigor and high frequency in all canopies but is less tolerant than fir and tends to be replaced by fir in the upper canopies of very old stands. Amabilis fir occurs with excellent vigor in all canopies and attains its best regional development on this association.

Average gross volumes per acre reached approximately 20,600 and 16,700 cubic feet respectively on the "Fern" and "Moss" associations. Another indication of the higher site quality of the "Fern" association resulted from segregation of sample plots into classes of good, fair, and poor site quality determined from maximum height of growth. On this basis 34, 42, and 24 per cent of the plots on the "Fern" association and 5, 29, and 66 per cent of the plots on the "Moss" association fitted into these three categories. Other comparisons and information about the two sites appear in Table I.

The average ages of hemlock and fir on most sample areas exceeded 300 years. Further reference to the basic data has demonstrated that more than one-third of the total volume was associated with trees older than 425 years. Ages considerably exceeded those previously encountered in sampling hemlock and fir in other regions in British Columbia (2, 5, 14, 19) and verify the over-mature condition of the dominant forest cover in the Kitimat region.

Early diameter growth of both fir and hemlock was greatly suppressed. The average fir at present in the 35-inch d.b.h. class grew only 6.0 inches during the first 100 years of its growth but added approximately twice this amount (11.9 inches) between the ages of 100 and 200 years; most trees in other diameter classes showed similar patterns of growth. Early suppression, with periodic and for the most part temporary release, seems to be characteristic of mature hemlock-fir climax forests in the Kitimat region.

TABLE I

BASIC STAND DATA PERTAINING TO SAMPLE AREAS OF LIVING MATURE WESTERN HEMLOCK AND AMABILIS FIR IN THE KITIMAT REGION BRITISH COLUMBIA

Locality	Elevation (feet)	Number of plots	Number of trees		Average d.b.h. (inches)		Average age (years)	
			Fir	Hemlock	Fir	Hemlock	Fir	Hemlock
			FERN ASSOCIATION					
Kitsumgallum Lake	1400	7	56	82	28.9	26.1	316	311
Andalas Creek	600	6	38	53	31.1	28.6	318	324
Pine Lake	700	12	66	111	29.8	31.8	376	372
Total or average	872	25	160	246	29.8	29.2	343	341
			MOSS ASSOCIATION					
Kitsumgallum Lake	1400	8	60	88	25.8	26.5	324	344
Andalas Creek	600	9	113	76	26.6	23.6	280	273
Clearwater Lake	750	11	91	86	23.8	30.2	303	368
Total or average	887	28	264	250	25.5	26.9	297	331
Total or average	880	53	424	496	27.1	28.1	314	335

Among 35-inch fir, some trees reached 12.9 inches during the first 100 years of growth, or twice the average for this diameter class. Further, on several plots at Andalas Creek trees had died *circa* 1800, released the then-existing understory, and provided partial open-growth conditions for a new forest. This latter forest reached a d.b.h. of approximately 15 inches in 100 years, compared with only 6.0 inches during the same period in the residual overstory.

An analysis of sample areas failed to verify earlier reports of predominating age and diameter classes within the region. In the case of fir, for example, the percentage of trees contained in the 200, 250, 300, 350, and 400-year-age classes were 13, 18, 15, 20, and 15 per cent respectively; the percentage of trees in the 15, 20, 25, 30, and 35-inch d.b.h. classes were approximately 17, 18, 18, 19, and 14 per cent respectively. Thus the forests sampled may be characterized as all-aged and of variable diameter.

Based on the weighted average of the six sample areas, hemlock represented 54 per cent and fir 46 per cent of the total volume of the stand; no differences in the percentage by volume of hemlock or fir occurred between forest sites.

DECAY OF AMABILIS FIR

Basic Loss

An analysis of basic data showed that 27 dead amabilis fir accounted for 6,838 cubic feet, or 6 per cent of the total volume of fir. Dead trees were for the most part highly defective, containing on the average only 18 per cent of their gross volume in sound wood.

The average loss from decay in living fir amounted to 18.5 per cent and 28.9 per cent of the gross volume recorded on the "Moss" and "Fern" associations respectively; an average loss of 23.5 per cent occurred on combined sites. Extreme values ranged from 14 to 29 per cent and from 20 to 38 per cent on individual sample areas of the "Moss" and "Fern" associations. Analyses

demonstrated that these differences were related mainly to differences in the size and age of trees and to the varying occurrence of a relatively small number of highly defective trees.

Fungi Responsible for Decay

Although a number of fungi were associated with decay in living amabilis fir (Table II), very few occurred frequently and only one, *Echinodontium tinctorium*, was of outstanding importance (see Plate I). This fungus was responsible for 41 per cent of the total infections and 65 per cent of the total decay.

TABLE II

RELATIVE IMPORTANCE OF THE PRINCIPAL DECAY FUNGI OF LIVING AMABILIS FIR IN THE KITIMAT REGION

Associated decay and fungus	Infections		% of total decay
	Number	% of total	
Brown cubical rots			
Stereum abietinum Pers.	52	14.2	4.8
Fomes pinicola (Sw.) Cke.	7	1.9	2.2
Polyporus sulphureus Bull. ex Fr.	14	3.8	1.8
Other fungi	4	1.0	trace*
	77	20.9	8.8
White rots			
Echinodontium tinctorium E. & E.	149	40.7	64.9
Fomes pini (Thore ex Fr.) Karst.	29	7.9	13.0
Hericium sp.	13	3.5	4.8
Stereum sanguinolentum A. & S. ex Fr.	40	10.9	2.9
Fomes annosus Fr.	10	2.7	2.0
Poria subacida (Pk.) Sacc.	11	3.0	1.3
Polyporus tomentosus Fr.	3	0.8	0.3
Armillaria mellea (Vahl ex Fr.) Quél.	3	0.8	0.1
Other fungi	4	1.0	0.1
	262	71.3	89.4
Mixed and unknown	28	7.8	1.8

*trace—less than 0.1%.

Echinodontium tinctorium is reported to occur only in Asia and western North America. Its host range, however, is extensive and includes four genera and 13 species of the Coniferales (22).

Until recently, the distribution of *E. tinctorium* in British Columbia was regarded as sporadic (14, 21, 22). The fungus is now known, however, to have an extensive distribution more or less coincident with the range of susceptible hosts. Evidence (22) indicates that conditions of forest habitat influence its occurrence and severity. Limited information is available about the relative importance of *E. tinctorium* in specific areas of attack but available records indicate that the fungus may be responsible for severe damage in habitats which favor its development. Reportedly it has caused 45 per cent of the total decay in *Abies lasiocarpa* (Hook.) Nutt. in the Upper Fraser region (19) and 74 per cent of the total decay in this host in the southern interior region of British Columbia (5). The degree of attack reported in this study for *Abies amabilis* in the Kitimat region should not be considered unusual in susceptible *Abies* forests.

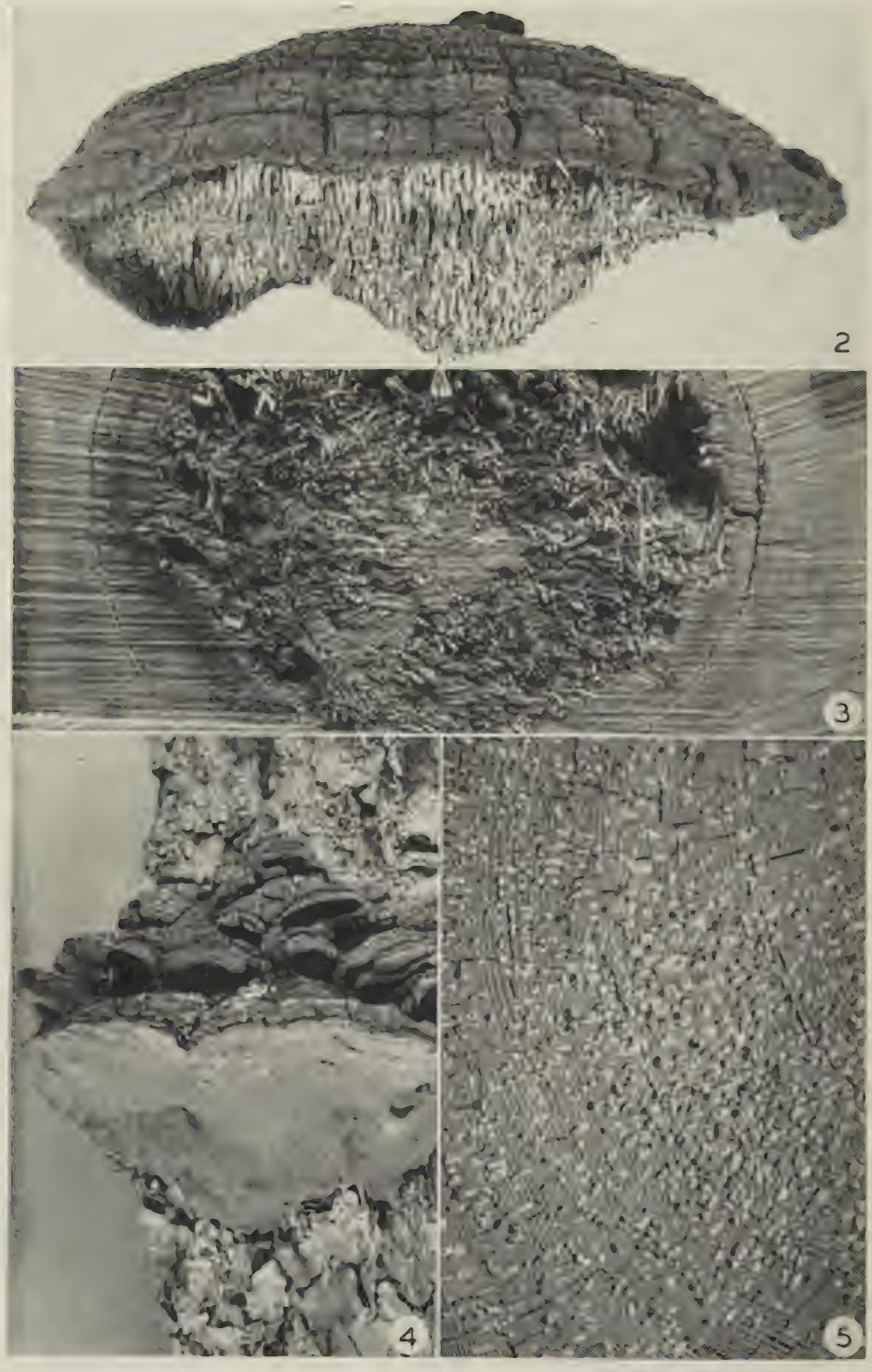


PLATE I

Echindontium tinctorium showed a uniform occurrence in the different sample areas; it was present on 24 of the 25 plots of the "Fern" association and on 23 of the 28 plots of the "Moss" association. A chi-square analysis demonstrated a significantly higher severity of infection ($P = <.05$) on the "Fern" site. Seventeen of the plots on this site for example had more than 40 per cent of their trees infected by *Echinodontium* but only eight of the plots on the "Moss" site displayed this amount of infection. Verification of this finding through the analysis of sub-plots of larger size would be warranted. *Echinodontium* sporophores were present on 76 trees, or 51 per cent of the total number infected by this fungus. No significant difference in the number of sporophore-bearing trees was apparent on the two sites.

Fomes pini (Thore ex Fr.) Karst. was the second most important decay-producing fungus encountered in fir; it was responsible for 8 per cent of the infections and 13 per cent of the total decay. This incidence and severity is noteworthy in view of previous evidence demonstrating a rare to infrequent occurrence of this fungus on *Abies* in North America. *Fomes pini* has been reported, for example, to cause only 1 per cent of the infections in *Abies amabilis* on the coast (6) and less than 3 per cent of the infections in *A. lasiocarpa* in the interior of British Columbia (2, 5, 19). Basham *et al.* have shown, moreover, that *Fomes pini* is responsible for less than 1 per cent of the total infections in *Abies balsamea* (L.) Mill. in eastern North America (1). Because it is unlikely that any of the host species mentioned have been examined over their full range of habitat conditions, conclusions about the relative susceptibility within the host genus *Abies* would be premature. Evidently the genus is only rarely attacked to the extent seen in the present sample.

Typical sporophores were readily observed on 62 per cent of all trees infected by *Fomes pini* (see Plate I). Trees bearing sporophores contained 71 per cent of the total volume of decay caused by *F. pini*; apparently the sporophores provided a reliable index to the frequency of occurrence and importance of this decay. No apparent differences in the relative occurrence of infected trees or trees with sporophores were noted on the two sites nor were any differences recorded in the average size or age of infected trees with and without sporophores; the average volume per infection, however, was significantly greater ($P<.05$) in the former group.

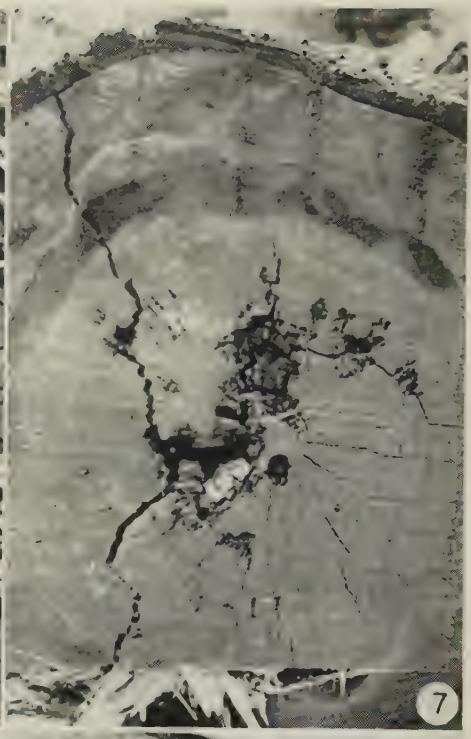
Stereum abietinum Pers. ranked third as a cause of loss in volume being responsible for 14 per cent of the infections and 5 per cent of the total decay (see Plate II). It was responsible for the most frequently occurring and important brown cubical rot encountered during the study and contributed more than one-half of the total volume of this class of decay. *Stereum abietinum* has only recently received attention as a cause of decay in living conifers (13) and to date has been encountered only in western forests. Sporophores were rarely observed on living fir although they were abundant on slash and other dead material.

Stereum sanguinolentum A. & S. ex Fr. was responsible for 11 per cent of the infections and 3 per cent of the total decay (see Plate II). Although it would be

---

PLATE I—FIG. 2. Sporophore of *Echinodontium tinctorium*.
FIG. 3. Cross section of brown stringy rot caused by *E. tinctorium*.
FIG. 4. Sporophores of *Fomes pini*.
FIG. 5. Cross section of white pitted rot caused by *F. pini*.

52292-0—3



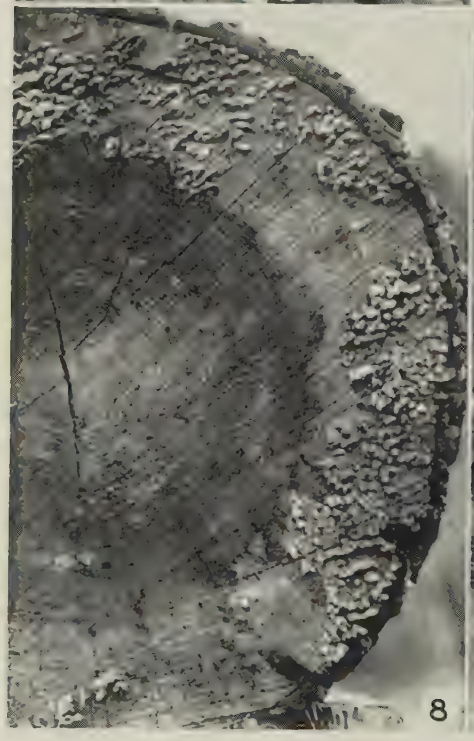


PLATE II

classed as a wood-destroying fungus of relatively minor importance in fir in the Kitimat region, it should be noted that it is an important cause of decay in *Abies* in the interior of British Columbia and in eastern North America. In *A. lasiocarpa*, for example, it is reported to cause 11 per cent of the total infections in the southern interior (5) and 34 per cent in the Upper Fraser region (2). In the latter region, it is also reported to cause 46 per cent of the total decay. McCallum (16) considered it to be one of the most important fungi attacking *A. balsamea* in Quebec and Basham *et al.* (1) have noted that it is responsible for 35 per cent of the total infections throughout the greater part of the range of this host in eastern North America.

In an advanced stage of decay, red heart rot caused by *Stereum sanguinolentum* appeared identical to brown stringy rot caused by *Echinodontium tinctorium* and, in the absence of sporophores, cultural tests were required for positive identification. The resupinate fruiting bodies of *Stereum sanguinolentum* were small and inconspicuous and observed only in felled trees.

The coral fungus, an apparently undescribed species of *Hericium*, was responsible for approximately 4 per cent of the infections and 5 per cent of the total decay. Fruiting bodies were large and conspicuous but fragile and nonpersistent, and were not observed on living trees during the course of the study. Although the coral fungus reportedly (13) causes a yellow-pitted decay, it was noted that this color may fade to white and under such circumstances the decay appeared identical to that caused by *Fomes pini*. Although it is possible that some infections attributed to *F. pini* were in fact caused by *Hericium*, it is unlikely that many such errors occurred since sporophores were present in the majority of the former infections. Also, successful cultural isolations were obtained in most cases where sporophores were lacking.

Most of the "other fungi" listed in Table II were of relatively minor importance in occurrence and amount of damage. Among these were *Odontia bicolor* (Alb. & Sch. ex Fr.) Bres., *Omphalia campanella* Fr., *Polyporus schweinitzii* Fr., *Poria tsugina* (Murr.) Sacc. & Trott., and *Poria weirii* Murr. The record of the latter fungus is of interest because it is believed to extend its previously known northern distribution.

External Indicators of Decay

Segregation of amabilis fir on the basis of the revised tree decadence classification established during the study demonstrated that recognition of specific tree abnormalities is a useful way to classify trees which vary in susceptibility to infection and in average volumetric loss from decay. Many trees designated as Residual were found to be sound but Suspect trees were mostly defective (Table III); 31 per cent of R, 74 per cent of S_1, and all of S_2 trees were infected. For the three classes decay averaged 6, 29, and 42 per cent. The frequency of occurrence of substantially decayed trees increased progressively from the R to S_2 class. Within the R, S_1, and S_2 classes, for example, 10, 58, and 99 per cent of the trees contained 10 per cent or greater cull and 1, 16, and 33 per cent of the

---

PLATE II—FIG. 6. Sporophores of *Stereum abietinum*.
FIG. 7. Cross section of brown cubical pocket rot caused by *S. abietinum*.
FIG. 8. Sporophores of *Stereum sanguinolentum*.
FIG. 9. Cross section of red heart rot caused by *S. sanguinolentum*.

52292-0—3½

Table III

CHARACTERISTICS OF THE TREE DECADENCE CLASSIFICATION IN AMABILIS FIR IN THE KITIMAT REGION, B.C.

(Basic data)

Tree class	Number of trees	Average d.b.h. (inches)	Average age (years)	Average decay (%)	Percentage of trees in class with volumes of decay exceeding:			
					0%	10%	30%	50%
R	242	24.4	272	6.2	31	10	4	1
S_1	88	28.8	353	29.5	74	58	42	16
S_2	94	32.4	387	42.3	100	99	78	33
D	27	28.2	327	82.5	100	100	100	100

trees in these classes were more than 50 per cent decayed. These data also demonstrate inter-class variation in percentage of loss. Thus, highly defective R trees, sound S_1 trees, and moderately defective S_2 trees sometimes occurred, but not frequently.

Although complete analyses of all defined abnormalities were not undertaken, scars were the most frequently occurring index to the S_1 class; more frequently basal scars were associated with decay than were those occurring in the upper bole. Attempts to relate the number and size of scars and the presence of other specific abnormalities to degree of loss were unsuccessful.

Ninety-four S_2 trees accounted for 14,040 cubic feet, or 59 per cent of the total volume of decay. Because trees of this class can be recognized before cutting, it is evident that only 41 per cent of the total decay in fir need be classed as hidden defect.

Diameter Relationships

Percentage of infection and volumetric loss in fir increased progressively with diameter between 15 and 50 inches (Table IV). Within this range, the percentage of infected trees increased from 21 to 100 and volumetric loss, as a

Table IV

THE RELATIONSHIP BETWEEN DIAMETER AND DECAY IN LIVING AMABILIS FIR IN THE KITIMAT REGION, B.C.

(Basic data)

Diameter breast height	Number of trees	Infected trees (%)	Average decay (%)	Percentage of trees with volume of decay exceeding:		
				10% of gross volume	30% of gross volume	50% of gross volume
15	71	21	6	15	8	1
20	78	29	7	17	10	6
25	78	51	16	35	27	11
30	82	63	17	44	30	10
35	58	84	26	59	45	19
40	41	95	35	83	56	32
45	14	100	35	86	57	29
50	2	100	47	100	100	50
Total or average	424	55	23	40	28	11

percentage of total tree volume, increased from 6 to 47 per cent. Considerable variation in decay was encountered within each diameter class. Thus, sound trees were recorded in most, and highly defective trees in all, diameter classes; at 35 inches for example, 16 per cent of the trees were sound, 41 per cent were less than 10 per cent defective, and 19 per cent were at least 50 per cent decayed. This variation should be considered normal in mature fir of the kind sampled; it may result partly from the variations in age, vigor, and susceptibility to infection of trees of the same size.

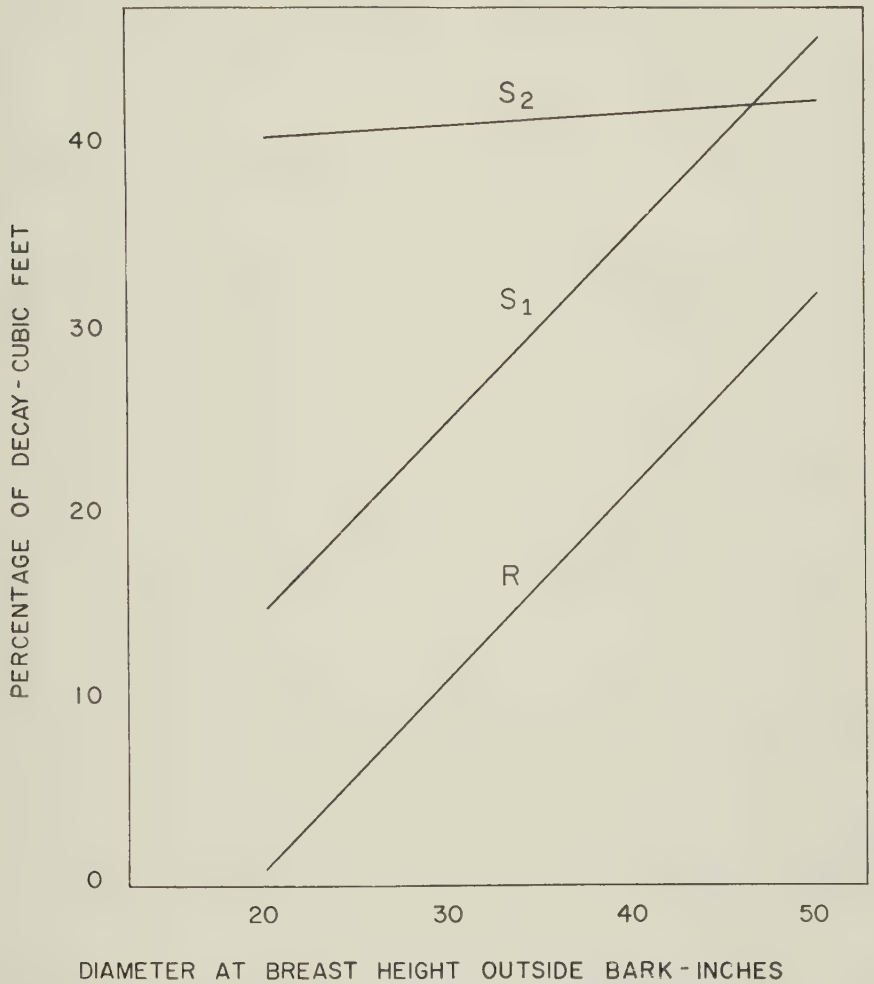


FIG. 10. Relationship between percentage of decay and diameter in tree decadence classes of amabilis fir in the Kitimat region:

Tree class	Regression formula	r	t_b	$s_{y.x}$
R	Y=1.03X−19.7	.....	.....	.....
S_1	Y=1.03X− 5.5	.35	3.53**	21.7
S_2	Y= .07 +39.0	.03	0.32	16.1

**Significant at the 1% level.

The relationships between percentage of decay and diameter for trees of the R, S_1, and S_2 classes are presented in Fig. 10. These relationships are based on rectilinear regressions for individual trees only in the case of the S classes. Comparable statistical treatment of the R class was not attempted because of the high proportion of sound trees. Percentage of decay for this latter class was determined through the regression of weighted average diameter class values and through subsequent harmonization with relationships derived for S trees. No significant second-degree parabolic curvilinearity of the data was apparent. Loss from decay increased from 1 to 32 per cent in R and from 15 to 46 per cent in S_1 trees between 20 and 50 inches d.b.h. Although some increase in amount of decay appeared to be associated with diameter within the S_2 class, tests failed to reveal any significant trend. An average of 42 per cent defect in S_2 trees should therefore be applied to all diameters.

Tests failed to reveal any significant second-degree parabolic curvilinearity in the regression of net volume on diameter. Further comparisons (Table V)

TABLE V

SUMMARY OF STATISTICS DERIVED THROUGH COMPARISON OF THE RECTILINEAR REGRESSIONS OF NET VOLUME ON DIAMETER IN AMABILIS FIR FOR TREE DECADENCE CLASSES ON FERN AND MOSS ASSOCIATIONS

Comparison: Net volume on diameter	Derived value of F
R (Fern) vs. R (Moss)	0.2
S_1 (Fern) vs. S_1 (Moss)	1.4
S_2 (Fern) vs. S_2 (Moss)	0.9
R (Combined sites) vs. S_1 (Combined sites)	45.8**
R (Combined sites) vs. S_2 (Combined sites)	155.1**
S_1 (Combined sites) vs. S_2 (Combined sites)	10.0**

**Significant at the 1% level.

failed to demonstrate any important differences in the slopes or adjusted means of rectilinear regressions segregated by forest association but did demonstrate significant differences between all tree decadence classes (Fig. 11).

Analyses demonstrated that a 28 per cent weighted average reduction in variance in the relation between net volume and diameter was effected through consideration of the tree decadence classes. These reductions were substantial, 41 and 31 per cent, in the case of R and S_2 classes but were negligible, 2 per cent, in the case of the S_1 class.

Age Relationships

Percentage of infection and volumetric loss in fir increased progressively with age (Table VI). No infection was observed in the small sample of trees under 150 years of age but from this age to 500 years the percentage of infection increased from 4 to 100 and the average volumetric loss from 0.1 to 39 per cent. Deviation from this trend was observed in the 550-year age class which has been attributed (2) to the presence of survivor trees which have escaped infection or severe volumetric loss. This hypothesis would appear to hold good in the sample studied in which few trees of advanced age occurred. It is of interest to

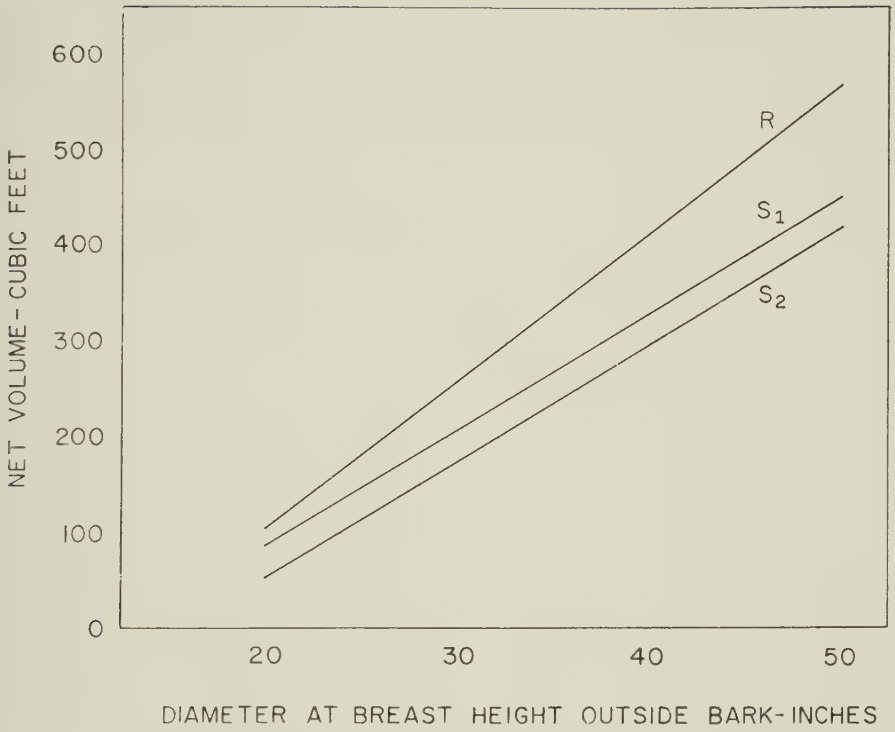


FIG. 11. Linear regressions of average net volume on diameter in tree decadence classes of amabilis fir in the Kitimat region:

Tree class	Regression formula	r	t_b	$s_{y.x}$
R	Y=15.3X—199.4	.90	46.9**	38.1
S_1	Y=12.0X—151.7	.67	13.1**	68.3
S_2	Y=12.4X—197.6	.66	13.3**	71.6

**Significant at the 1% level.

TABLE VI

THE RELATIONSHIP BETWEEN AGE AND DECAY IN LIVING AMABILIS FIR IN THE KITIMAT REGION, B.C.

(Basic data)

Age class	Number of trees	Infected trees (%)	Average decay (%)	Percentage of trees with volume of decay exceeding		
				10% of gross volume	30% of gross volume	50% of gross volume
100	8	0	0	0	0	0
150	24	4	trace*	0	0	0
200	54	15	3.2	6	4	2
250	76	35	5.7	17	8	3
300	64	48	10.4	31	23	3
350	84	75	22.4	51	37	15
400	64	89	30.9	70	47	23
450	28	93	41.5	89	82	32
500	16	100	39.5	94	50	31
550	6	83	29.1	83	67	0
Total or average	424	55	23	40	28	11

* Trace— less than 0·1%

observe the variation in percentage of decay and the increase in percentage of moderately and severely infected trees occurring in the various age classes. Although trees with more than 50 per cent of their gross volume destroyed first occurred in the 200-year age class, the number of trees with this degree of loss did not become important until 350 years or reach a significant proportion, 30 per cent, until 450 years.

Percentage of infection was found to increase progressively within the R and S_1 classes but no correlation was evident within S_2; all trees of this class were infected (Fig. 12). The relationships between percentage of decay and age for

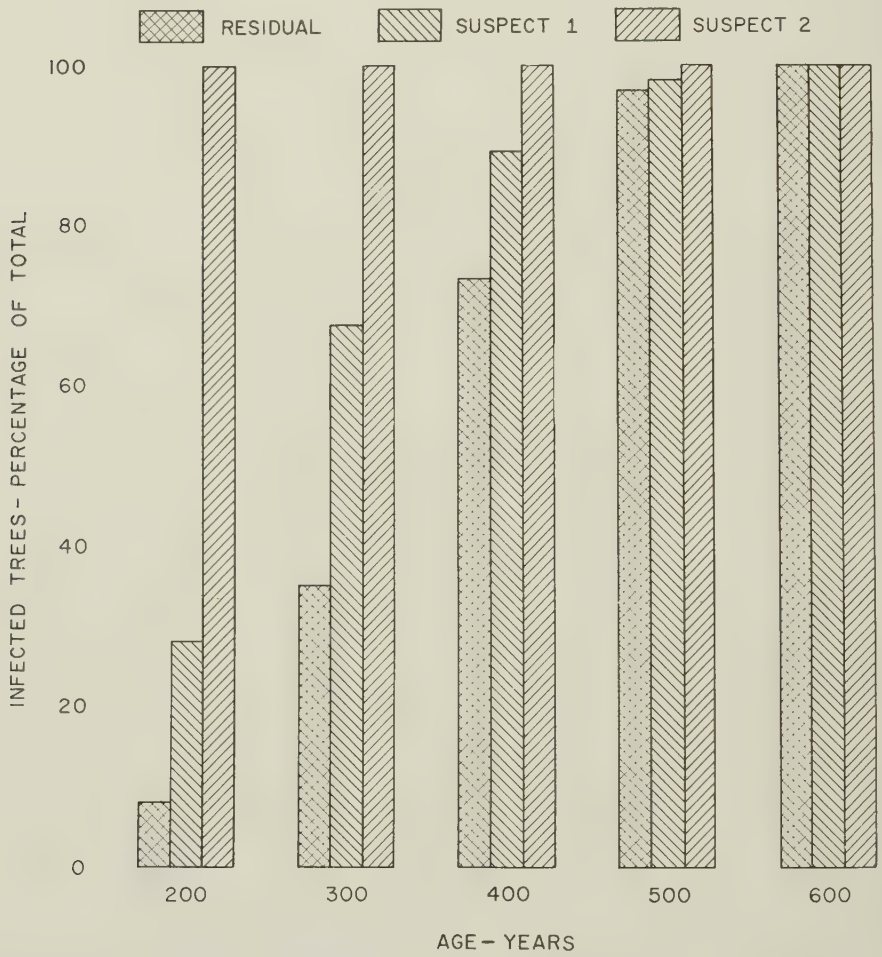


Fig 12. Relationship between percentage of infected trees and age in tree decadence classes of amabilis fir in the Kitimat region.

each of the tree decadence classes are presented in Fig. 13. These relationships are based on weighted average values derived for 50-year age classes in the case of R trees, and on the values derived from individual tree measurements in the case of the S classes. Loss from decay increased from 0.2 to 15 percent in R, from 3.5 to 44 per cent in S_1, and from 40.5 to 41.5 per cent in S_2 trees between

the 200- and 500-year age classes respectively. Tests demonstrated that the indicated trend with S_2 trees lacked significance; an average of 42 per cent defect should be applied to this class at all ages within the range 150-550 years.

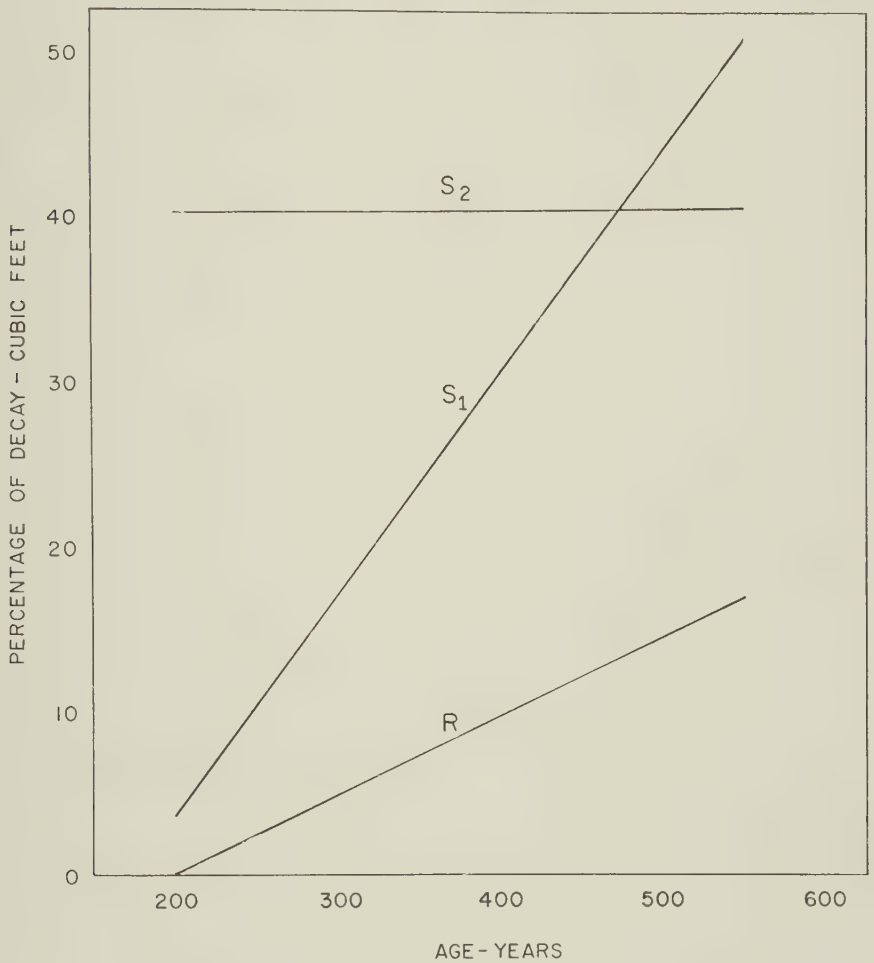


FIG. 13. Linear regressions of percentage of decay on age in tree decadence classes of amabilis fir in the Kitimat region:

Tree class	Regression formula	r	t_b	$s_{y.x}$
R	Y=.049X— 9.615	.....	.....	.....
S_1	Y=.136X—23.56	.51	5.55**	19.9
S_2	Y=.002X+40.18	.01	0.67	16.1

**Significant at the 1% level.

Correlation Analyses

Multiple linear correlation analyses were undertaken to provide a predicting mechanism for stand defect in fir. Preliminary analyses were undertaken on the "Fern" association with the variables Z (percentage of stand defect), X_1 (R stand volume/total stand volume, per cent), X_2 (S_2 stand volume/S_1S_2 stand

volume, per cent), and X_3 (average stand age). A multiple correlation coefficient of .82 was calculated, which shows that 67 per cent of the total variation in stand defect resulted from these variables. Correlated singly, however, X_1 explained 64 per cent of the total variation. These data thus illustrated that average stand age and the relative proportion of S_2 trees added little to the multiple linear correlation and so demonstrated that essentially the single variable X_1 is just as precise a predicting mechanism. The simple correlations of Z on X_1 were not found to differ significantly ($P > .05$) on the "Fern" and "Moss" associations and the data were combined to provide a correlation independent of site (Fig. 14). In this latter correlation the standard deviation

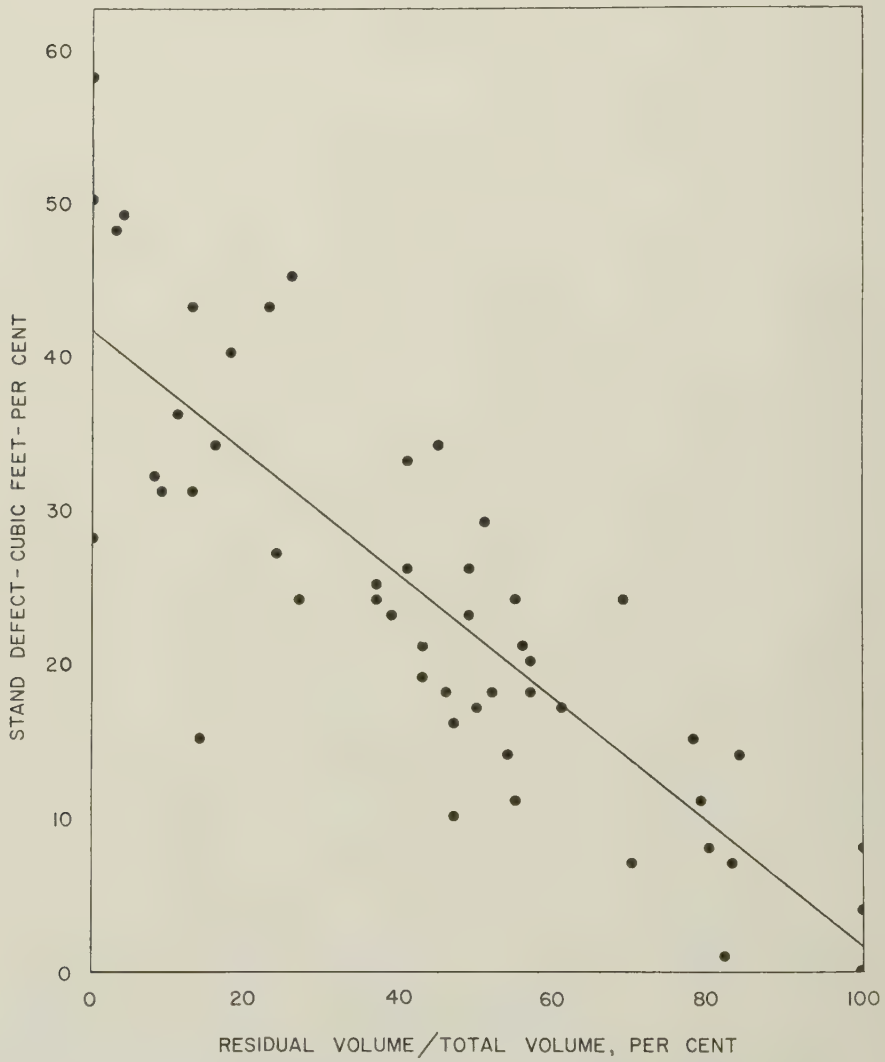


Fig. 14. Relationship between percentage of stand defect and the volume of Residual trees expressed as a percentage of total stand volume in amabilis fir in the Kitimat region. Linear regression formula, $Z = -.397X + 41.46$, correlation index .84, standard error of estimate ± 7.3.

of z and standard error of estimate of Z_{X1} amounted to 13.4 and 7.3 respectively. These statistics demonstrate that 70 per cent of the error variance was eliminated through use of the indicated regression, that is, that the regression was approximately 3.3 times more efficient than the regional average cull factor, $\bar{z}$, in estimating stand defect.

Further correlation analyses were undertaken to determine the relative efficiency of tree age (X_4) and diameter (X_5) in the estimation of individual tree defect (D). Tests of this nature undertaken within the S_1 class for combined site types demonstrated correlation indices of .51 and .35 for D_{X4} and D_{X5} respectively. Age was therefore more than twice as efficient an index as diameter in predicting defect in this class. No improvement in efficiency was gained through multiple correlation; the correlation coefficient obtained in the linear regression of D on $X_{4,5}$ amounting to .51 equals in value the correlation index derived in the simple regression of D on X_4. The high correlation index determined between age and diameter (.71) might explain the failure to gain improvement in this case.

DECAY OF WESTERN HEMLOCK

Basic Loss

An analysis of the basic data demonstrated the occurrence of 55 dead hemlock. These trees accounted for 17,440 cu. ft., or 13 per cent, of the total recorded volume of hemlock. Dead trees were for the most part highly defective, containing on the average only 19 per cent of their gross volume in sound wood.

The loss from decay in living hemlock averaged 31 per cent on "Fern" and "Moss" associations. Minimum and maximum values determined for separate sample areas reached 22 and 36 per cent.

Fungi Responsible for Decay

A number of fungi were isolated from their association with decay in western hemlock but only *Fomes pini* occurred frequently and caused severe damage; it was responsible for 24 per cent of the infections and 48 per cent of the total decay (Table VII).

White pitted rot caused by *F. pini* is known to be an important decay of western hemlock. It has reportedly caused 13 per cent of the total decay in hemlock on Vancouver Island (6) and on the Queen Charlotte Islands (13), 16 per cent of the decay in hemlock in western Oregon and Washington (10), and 25 per cent of the decay in hemlock in the Upper Columbia region (14). Kimmey (15), on the other hand, has reported that it was responsible for only 1 per cent of the infections and decay in hemlock in Alaska. The recorded severity of *F. pini* in the present sample thus far exceeded the damage reported on this host in other regions.

Fomes pini was present on 24 of the 25 plots of the "Fern" and 25 of the 28 plots of the "Moss" association. Sporophores were present on 72 per cent of the trees infected by this fungus. No differences in severity of infection or in the occurrence of sporophore-bearing trees were noted between sites. The severity of white pitted rot has been correlated with site in other regions (4). In hemlock in the Upper Columbia region (14) it caused 11 per cent of the infections and 15 per cent of the decay on below-average, and 25 per cent of the infections and 41

TABLE VII

RELATIVE IMPORTANCE OF THE PRINCIPAL DECAY FUNGI OF LIVING WESTERN HEMLOCK IN THE KITIMAT REGION

Associated decay and fungus	Infections		% of total decay
	Number	% of total	
Brown cubical rots			
Stereum abietinum Pers.	69	11.8	5.8
Fomes pinicola (Sw.) Cke.	37	6.3	4.6
Polyporus sulphureus Bull. ex Fr.	3	0.5	0.3
Omphalia campanella Fr.	2	0.3	0.1
Other fungi	4	0.7	0.3
	115	19.6	11.1
White rots			
Fomes pini (Thore ex Fr.) Karst.	141	24.1	47.9
Echinodontium tinctorium E. & E.	102	17.5	19.8
Stereum sanguinolentum A. & S. ex Fr.	106	18.1	6.6
Armillaria mellea (Vahl ex Fr.) Quél.	24	4.1	2.6
Poria tsugina (Murr.) Sacc. & Trott.	20	3.4	2.6
Fomes annosus Fr.	9	1.6	1.1
Polyporus tomentosus Fr.	3	0.5	0.6
Poria subacida (Pk.) Sacc.	2	0.3	0.6
Hericium sp.	4	0.7	0.1
Other fungi	3	0.5	0.1
	414	70.8	82.0
Mixed and unknown	56	9.6	6.9

per cent of the decay on above-average sites measured in terms of relative total height at maturity. No significant trends of this nature were determined with the present data. The explanation for the lack of significant correlation with site is believed to be related to the narrow range of sites examined. It is equally possible, however, that height growth may be an inadequate measure of the habitat factors influencing the incidence and severity of this fungus in the Kitimat region.

Echinodontium tinctorium ranked second in order of importance, being responsible for 17 per cent of the total infections and 20 per cent of the total decay. Although brown stringy rot caused by *E. tinctorium* has been recognized as one of the most important decays of western hemlock in Idaho (23) and in the interior of British Columbia (14), only recently has it been found to have a distribution in the coastal and Cascade regions. The present study confirms the latter finding and demonstrates the ability of the fungus to cause substantial damage to hemlock in the forest associations examined. *Echinodontium tinctorium* was present on 23 of the 25 plots of the "Fern" and 22 of the 28 plots of the "Moss" association. A slightly higher severity of infection was recorded on the "Fern" association, but the difference was not significant ($P > .05$). Sporophores did not occur frequently and were present on only 27 per cent of the total number attacked by this fungus. No difference in the number of sporophore-bearing trees was apparent on the two sites.

Red heart rot caused by *Stereum sanguinolentum* was associated with 18 per cent of the infections and 7 per cent of the total decay. This fungus is not reported as a cause of decay in hemlock in Alaska (15), the Queen Charlotte Islands (13), Vancouver Island (6), or western Oregon and Washington (10). In

the interior of British Columbia it is responsible for only 2 per cent of the infections and 0.2 per cent of the total decay (2). The present study has thus demonstrated an unusually high incidence of occurrence and severity for this fungus.

Brown cubical rots were responsible for only 11 per cent of the total decay; *Stereum abietinum* accounted for more than 50 per cent and *Fomes pinicola* (Sw.) Cke. for more than 40 per cent of this decay. The latter fungus is recognized as one of the most important agents causing deterioration of killed stands in western North America. The minor importance attached to it in the present study may be attributed to the rejection from analysis of dead trees.

Armillaria mellea (Vahl ex Fr.) Quél. and *Poria tsugina* were each responsible for approximately 3 per cent of the total decay. It is of interest to note that *Armillaria mellea* has recently been classed as one of the most important decay-producing fungi in Alaska (15) but was formerly believed to be of little consequence in mature forests. *Poria tsugina* was found to gain entrance to hemlock largely through branch and trunk infections of dwarf mistletoe (*Arceuthobium campylopodum* f. *tsugensis* (Rosendahl) Gill), thus confirming previous knowledge of the association of this fungus with mistletoe.

Most of the remaining fungi associated with decay in hemlock were of relatively minor importance, viz., *Flammula connissans* Fr. *sensu* Ricken, *Fomes annosus* Fr., *Hericium* sp., *Omphalia campanella, Pholiota adiposa* (Fr.) Quél., *Polyporus circinatus* Fr., *P. schweinitzii, P. resinosus* Schrad. ex Fr., *P. sulphureus* Bull. ex Fr., *P. volvatus* Pk., *Poria subacida* (Pk.) Sacc., *P. weirii*, and *Stereum chailletii* (Pers. ex Fr.) Fr.

External Indicators of Decay

Western hemlock demonstrated a high frequency of occurrence of sound trees in the R class and a high frequency of infected trees in the S classes (Table VIII); only 24 per cent of R trees were infected but 79 per cent of S_1 and 100 per

Table VIII

CHARACTERISTICS OF THE TREE DECADENCE CLASSIFICATION IN WESTERN HEMLOCK IN THE KITIMAT REGION, B.C.

(Basic data)

Tree class	Number of trees	Average d.b.h. (inches)	Average age (years)	Average decay (%)	Percentage of trees in class with volumes of decay exceeding:			
					0%	10%	30%	50%
R	174	21.7	270	6.9	24	9	5	1
S_1	179	30.6	368	27.4	79	48	31	12
S_2	143	32.6	377	47.8	100	95	76	33
D	55	32.6	379	81.3	96	96	90	85

cent of S_2 trees contained measurable decay which averaged 7, 27, and 48 per cent for the three classes. Although 9 per cent of R trees had more than 10 per cent of their volume destroyed, only 1 per cent were more than 50 per cent defective. The S_1 and S_2 trees presented substantially different patterns of decay severity; volume of decay exceeding 10 per cent and 50 per cent respectively totalled 48 per cent and 12 per cent for S_1 and 95 and 33 per cent for S_2 trees.

These data showed that the probabilities of trees occurring with substantial volumes of decay increased from the R to S_2 classes. For trees having more than 50 per cent of their volume destroyed, values of 1, 12, and 33 per cent were determined for R, S_1, and S_2 trees, the result partly of differences in age. Sixty-four per cent of R but only 19 per cent of S trees were less than 276 years of age and fewer than 3 per cent of R but more than 20 per cent of S trees were older than 425 years. A significantly higher proportion of small trees fell into the R class.

Seventy-three per cent of the S_1 trees were so classified because of the presence of scars, 10 per cent as a result of frost cracks, 10 per cent because of trunk infections of mistletoe, and 7 per cent for other reasons. A total of 324 scars were recorded. The decay in scarred trees averaged 20 per cent compared with 11 per cent in R trees of the same age; thus, the presence of scars was associated with higher than average volumes of decay.

Although most decay in hemlock occurred in the upper half of the trees, substantial loss sometimes occurred in basal logs partly as the result of root and basal scar infections and partly from the downward extension of trunk rots.

The S_2 trees accounted for 32 per cent of the total decay recorded in living hemlock and even if trees of this class were recognizable before cutting most of the decay would be classed as hidden defect.

Diameter Relationships

Percentage of infection and average volumetric loss in hemlock increased progressively with diameter between 15 and 55 inches (Table IX). Within this range the percentage of infected trees increased from 31 to 100 and volumetric loss, as a percentage of total tree volume, increased from 4 per cent to approximately 47 per cent.

The relative proportion of trees containing low, moderate, and excessive amounts of decay varied with tree diameter. At 15 inches 14, 4, and 1 per cent

Table IX

THE RELATIONSHIP BETWEEN DIAMETER AND DECAY IN LIVING WESTERN HEMLOCK IN THE KITIMAT REGION, B.C.

(Basic data)

Diameter breast height	Number of trees	Infected trees (%)	Average decay (%)	Percentage of trees with volume of decay exceeding:		
				10% of gross volume	30% of gross volume	50% of gross volume
15	71	31	4	14	4	1
20	101	37	8	22	16	5
25	86	65	13	35	23	2
30	85	79	21	51	33	8
35	64	91	38	83	66	27
40	43	93	41	86	60	35
45	29	100	47	90	72	55
50	12	100	47	92	92	42
55	5	100	43	100	80	40
Total or average	496	66	31	48	34	14

of the trees had respectively more than 10, 30, and 50 per cent of their volume destroyed but at 55 inches the corresponding ratios reached 100, 80, and 40 per cent of the trees. Although fewer than 10 per cent of the trees up to 30 inches d.b.h. were more than 50 per cent defective, a marked increase in the proportion of cull trees occurred at 35 inches and beyond this diameter an average of 43 per cent of the trees were so affected.

The relationships between percentage of decay and diameter for R, S_1, and S_2 trees appear in Fig. 15. These relationships are based on rectilinear regressions

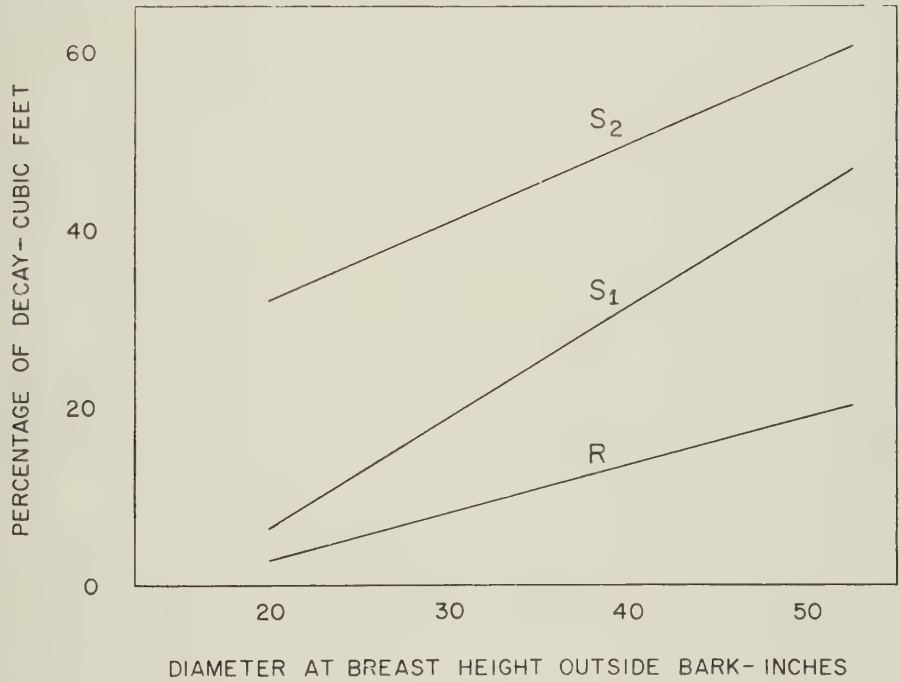


FIG. 15. Linear regressions of percentage of decay on diameter in tree decadence classes of western hemlock in the Kitimat region:

Tree class	Regression formula	r	t_b	$s_{y.x}$
R	Y= .46X— 7.61	.....	.....	.....
S_1	Y=1.22X—17.96	.51	7.87**	19.3
S_2	Y= .88X+14.32	.40	5.29**	17.9

**Significant at the 1% level.

for individual trees of the S classes and on weighted average diameter class values for R trees. No curvilinearity of the data was apparent. Loss from decay in trees between 20 and 50 inches d.b.h. increased from 3 to 10 per cent in R, from 6 to 44 per cent in S_1, and from 32 to 58 per cent in S_2 trees.

Tests failed to reveal any significant curvilinearity in the regression of net volume on diameter. Further tests failed to demonstrate any significant differences in the slopes or adjusted means of rectilinear regressions segregated by

forest association, but did demonstrate (Table X) significant differences between tree decadence classes (Fig. 16). Analyses demonstrated that a 20 per cent

TABLE X

SUMMARY OF STATISTICS DERIVED THROUGH COMPARISON OF THE RECTILINEAR REGRESSIONS OF NET VOLUME ON DIAMETER IN WESTERN HEMLOCK FOR TREE DECADENCE CLASSES ON FERN AND MOSS ASSOCIATIONS

Comparison: Net volume on diameter	Derived value of F
R (Fern) vs. R (Moss)	2.8
S_1 (Fern) vs. S_1 (Moss)	1.8
S_2 (Fern) vs. S_2 (Moss)	0.9
R (Combined sites) vs. S_1 (Combined sites)	8.3**
R (Combined sites) vs. S_2 (Combined sites)	89.6**
S_1 (Combined sites) vs. S_2 (Combined sites)	51.9**

**Significant at the 1% level.

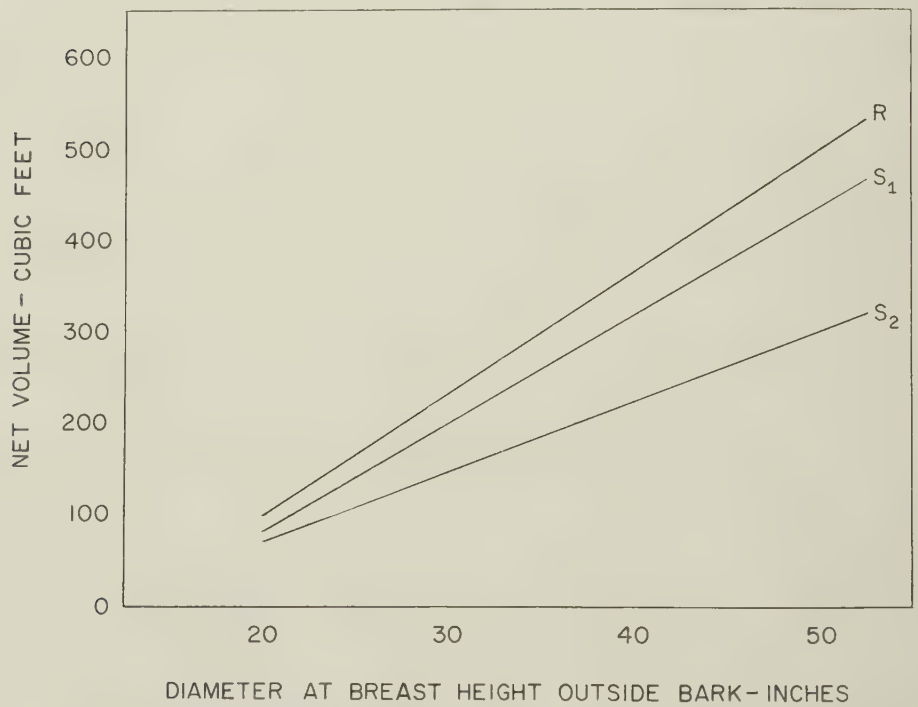


FIG. 16. Linear regressions of average net volume on diameter in tree decadence classes of western hemlock in the Kitimat region:

Tree class	Regression formula	r	t_b	$s_{y.x}$
R	Y=12.5X—148.7	.93	30.67**	35.5
S_1	Y=11.7X—150.9	.81	18.72**	77.6
S_2	Y= 7.7X— 83.8	.75	13.64**	61.3

**Significant at the 1% level.

weighted average reduction in variance in the relationship between net volume and diameter was introduced through consideration of the tree decadence classes. These reductions were substantial, amounting to 50 and 34 per cent in the R and S_2 classes respectively but were negligible, 3 per cent, in the case of the S_1 class.

Age Relationships

Percentage of infection and volumetric loss in hemlock increased progressively with age (Table XI). No infection was observed in the relatively small sample of 100-year-old hemlock. Between 150 and 500 years, however,

TABLE XI

THE RELATIONSHIP BETWEEN AGE AND DECAY IN LIVING WESTERN HEMLOCK IN THE KITIMAT REGION, B.C.

(Basic data)

Age class	Number of trees	Infected trees (%)	Average decay (%)	Percentage of trees with volume of decay exceeding:		
				10% of gross volume	30% of gross volume	50% of gross volume
100	6	0	0	0	0	0
150	13	8	trace*	0	0	0
200	16	19	1	6	0	0
250	122	33	5	16	10	1
300	64	59	13	31	19	3
350	93	83	26	54	34	11
400	100	90	36	80	61	22
450	59	91	45	78	63	42
500	13	100	48	100	85	38
550	4	100	66	100	100	75
600	5	100	38	60	40	40
650	1	100	5	0	0	0
Total or average	496	66	31	48	34	14

* Trace— less than 0·1%

incidence of decay increased from 8 to 100 per cent and average volumetric loss from approximately 0.1 to 48 per cent. Considerable variation in percentage of decay was observed beyond 500 years. It is of interest to note that only 12 of the 157 trees between 100 and 250 years of age had more than 30 per cent of their volume destroyed and that only one tree was more than 50 per cent defective. It is noteworthy that approximately 30 per cent of the hemlock fell in the age classes mentioned. A marked increase in the percentage of cull trees occurred at approximately 350 years and beyond this age an average of 31 per cent of the trees were culls.

Percentage of infection was found to increase progressively within the R and S_1 classes but no correlation was evident within S_2; all trees of this class were infected (Fig. 17).

The relationships between percentage of decay and age for each of the tree decadence classes are presented in Fig. 18. These relationships are based on weighted average values derived for 50-year age classes in the case of R trees and

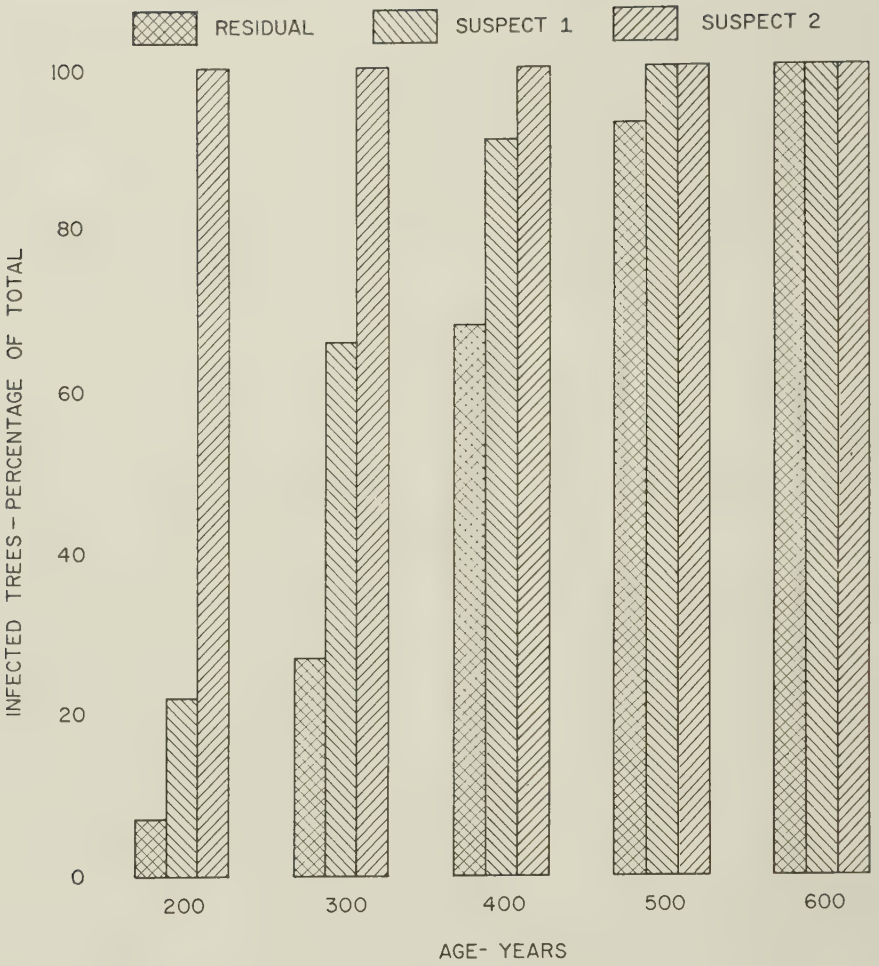


FIG. 17. Relationship between percentage of infected trees and age in tree decadence classes of western hemlock in the Kitimat region.

on individual tree values in the case of the S classes. Loss from decay in trees between 250 and 600 years of age increased from 2 to 31 per cent in R, from 3 to 49 per cent in S_1, and from 28 to 72 per cent in S_2 trees.

Correlation Analyses

Multiple linear correlation analyses were made on living hemlock between the variables Z (percentage of stand defect), X_1 (R stand volume/total stand volume, per cent), and X_2 (S_2 stand volume/S_1S_2 stand volume, per cent) based on values derived from $\frac{1}{2}$ acre sample plots on combined site types. A correlation coefficient of .56 was determined, demonstrating that only 31 per cent of the total variation in decay was explained by these variables. Correlated singly, X_1 explained 29 per cent of the variation. The standard deviation of z and standard error of estimate of Z_{X1} amounted to 10.2 and 8.9 respectively (Fig. 19). These statistics demonstrate that the indicated regression was only slightly more

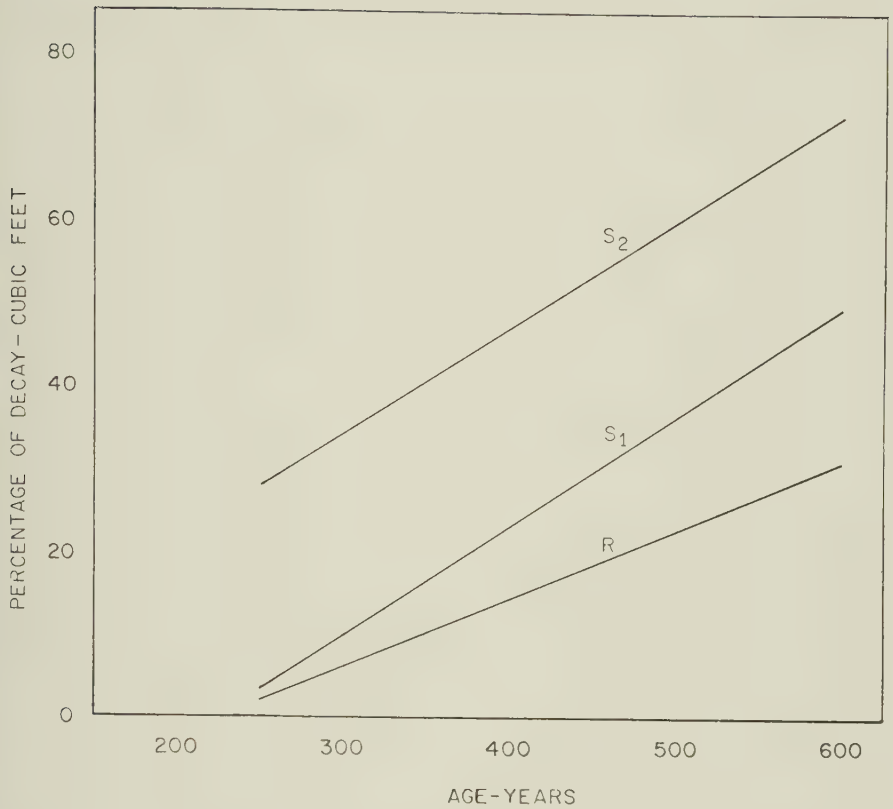


FIG. 18. Linear regressions of percentage of decay on age in tree decadence classes of western hemlock in the Kitimat region:

Tree class	Regression formula	r	t_b	$s_{y.x}$
R	Y = .083X −18.7	.....	.....	.....
S_1	Y = .032X—29.6	.45	6.66**	20.0
S_2	Y = .128X— 6.0	.47	6.30**	17.3

**Significant at the 1% level.

efficient than the average regional cull factor, $\bar{z}$, in estimating stand defect. A substantial difference was encountered between the "Fern" and "Moss" associations, simple regressions in the former explaining 53 per cent and in the latter 23 per cent of the sub-sample variation. The reasons for the relative lack of correlation in the "Moss" association were not apparent.

Further analyses demonstrated correlation indices of .45 for tree age (X_4) and .51 for tree diameter (X_5); diameter was essentially as reliable an index as age. Standard errors of estimate for D_{X4} and D_{X5} were 20.0 and 19.3 respectively. No improvement was gained through multiple correlation of these variables; the correlation coefficient derived in the linear regression of D on $X_{4,5}$ amounted to .52, a value equivalent to the correlation index in the simple regression of D on X_5.

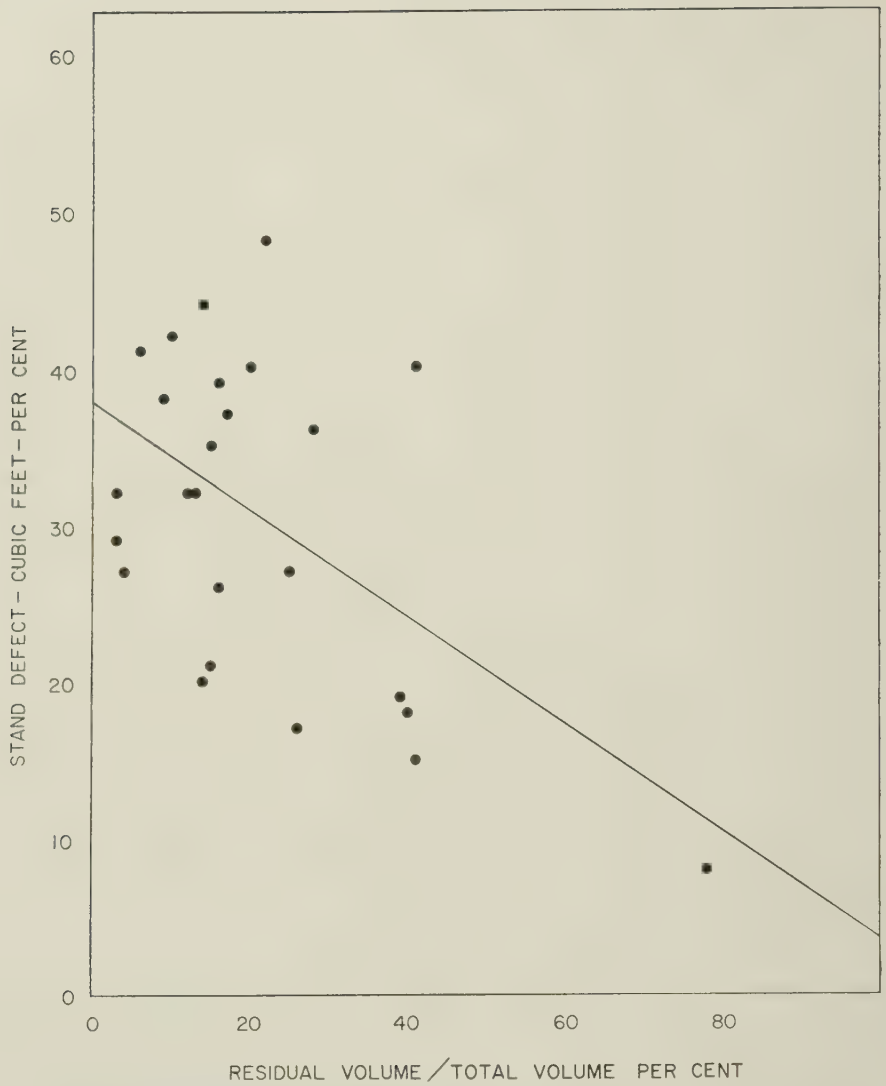


FIG. 19. Relationship between percentage of stand defect and the volume of Residual trees expressed as a percentage of total stand volume in western hemlock in the Kitimat region. Linear regression formula, $Z = -.34X + 37.7$, correlation index .54, standard error of estimate, ± 8.9.

Discussion

The method of sampling used in this study appears to offer distinct advantages when making field examinations for comparative host susceptibility. By following this procedure, it is largely possible to avoid the influence of intra-regional variations in decay and to sample each species under similar conditions of forest habitat. The forest association classification employed would appear to offer the advantages of ease of recognition and thoroughness of detail, although it might take further study to verify which specific habitat factors exert the greatest direct influence on the host and forest fungus under consideration.

Certainly this classification holds greater promise than site classifications based on the heights of trees at maturity; it would be entirely by chance if the factors which control height growth of trees equally influenced the occurrence and severity of wood-destroying fungi. To improve sampling methods, the investigator might increase the size of plots to provide larger sub-samples of each host, extend sampling to include a wider range of forest associations, and study specific tree abnormalities in more detail. Western species of true fir have long been known to be susceptible to *Echinodontium tinctorium* but only recently have studies shown that *Abies amabilis* is infected by this fungus more or less throughout its range. This investigation makes it clear for the first time that the fungus infection may lead to substantial loss of volume and that it may assume a dominant role in the deterioration of fir on at least two of the sites favorable to its development.

Although *Echinodontium tinctorium* was responsible for more than 60 per cent of the total decay in fir, it caused only 20 per cent of the decay in hemlock, a difference which proved to be significant ($P < .01$). Sampling was restricted to mixed fir-hemlock forests and all sample plots were clear cut to both species therefore intra-regional differences in decay would have exerted little if any influence on this difference between hosts. Also *Echinodontium tinctorium* was present on 51 of the 53 sample plots and thus we may assume that inoculum was available to infect each host. For these reasons, recorded differences between hosts appear to result from differences in host susceptibility; either fir is inherently more susceptible or some habitat factors induced this difference by modifying the host.

Significant differences ($P < .01$) between tree species were also evident in the case of attack by *Fomes pini*. This fungus was responsible for 13 per cent of the total decay in fir and 48 per cent in hemlock. Important differences were also recorded in the incidence of infection. *Fomes pini*, for example, was present in hemlock on all 12 sample plots of the "Fern" association at Pine Lake. Even though fir was present on all of these plots, it was attacked in only two cases. These differences in occurrence and severity may be related either to inherent or induced differences between fir and hemlock.

The conclusion that *Fomes pini* attacks *Abies* spp. only infrequently in North America would appear inescapable. However, the incidence of this fungus on fir in the Kitimat region and the likelihood that few members of the genus have been examined over their full range of ecological association should preclude any inference that *F. pini* is not in fact capable of causing moderate or even severe damage to this host genus elsewhere.

The amount of total defect and the relative importance of the principal wood-destroying fungi differed from those previously encountered in coast and interior regions of British Columbia. These differences seem to add support to the thesis (22) that a transitional zone exists in the Cascade region and that this zone has certain characteristics in common with and others distinct from coast and interior regions. Thomas (22), for example, has shown that most "Fern" and "Moss" associations of the Kitimat region are located near the heads of coastal channels and in coastal trenches which penetrate inland and therefore are subjected to modified maritime and interior climates.

No major differences in total defect or in the occurrence of specific fungi were recorded between the "Fern" and "Moss" associations. However, it does

not necessarily follow that forest habitat has no effect on forest fungi as differentiated in this classification. In fact the contrary hypothesis has been demonstrated. The present data may have failed to corroborate these latter findings because of only small differences between the particular sites selected. The "Fern" and "Moss" associations can be regarded as two closely related sites of the series on which fir and hemlock occur; it is likely that greater differences in the occurrence of certain forest fungi would have resulted had more diverse sites been selected.

A previously established (12) tree decadence classification designed to help predict defect in individual trees and total stands was found to apply to both fir and hemlock in the Kitimat region. In both species the average volumetric losses in Residual, Suspect, and Dead trees reached approximately 6, 36, and 82 per cent respectively—proof that these three distinct classes of trees contained substantially different average volumes of defect. The smaller average amount of decay recorded in Residual trees likely resulted partly from their smaller average size and age, and partly from the absence of apparent mechanical and other damage through which wood-destroying fungi could enter.

A more detailed analysis of the basic data demonstrated that Suspect trees could be segregated into sub-classes (defined here as S_1 and S_2) and established that these sub-classes differed in occurrence and severity of decay. This extension of the classification made it possible to determine that most of the decay was present in a relatively small number of highly defective trees. The S_2 class, for example, contained 66 per cent of the total number of cull trees and 59 per cent of the total decay encountered in fir. Rejection of the S_2 class would reduce the average defect in living fir and hemlock to 14 and 21 per cent respectively. Complete rejection of this class would not be warranted however; a substantial number of trees were only moderately defective. It was not possible with the present data to differentiate between moderately and highly defective S_2 trees prior to felling. But it was determined that the frequency of occurrence of highly defective trees was correlated with tree diameter; 25, 50, and 80 per cent of the S_2 hemlock in the 30, 40, and 50-inch d.b.h. classes were more than 50 per cent defective.

The tree decadence classification was found to be of value in estimating total stand defect. Calculated precisions in estimating the percentage of stand defect were $\pm$ 7.3 in fir and $\pm$ 8.9 in hemlock. These values demonstrate improvement over the average regional cull factors with calculated precisions of $\pm$ 13.4 in fir and $\pm$ 10.2 in hemlock.

Approximately 16 per cent of the fir and 27 per cent of the hemlock were scarred from falling trees, animals, and other agents; many of these were small but others extended for considerable distances. Apart from their importance as entrance courts for fungi, the larger scars caused direct damage. Limitations in the design and sampling of the present study did not permit a complete analysis of the significance of scars, yet there is ample evidence from other work to indicate that early infection and rapid deterioration may follow their development. Basal scars are known (24) to be of greater significance than trunk scars and it should be noted that over 70 per cent of the scars in fir and hemlock were situated in the first 16 feet of the bole.

Less than 10 per cent of the total infections in fir and hemlock resulted from root-rotting fungi. The low incidence of such fungi appears to support previous evidence of their occurrence in mature forests. *Poria weirii*, for example, is responsible (7) for an important root rot of immature Douglas fir, *Pseudotsuga menziesii* (Mirb.) Franco, yet has been reported (20) to cause only 0.2 per cent of the infection in mature stands of this species. This same fungus reportedly (6) is responsible for less than 3 per cent of the infections in mature western hemlock, another preferred host. The explanation for the apparently decreased importance of root-rotting fungi in mature forests of susceptible hosts is not known. It does not necessarily follow that new forests in the Kitimat region will be any more susceptible to root-rotting fungi than existing mature forests but this possibility should not be overlooked in planning forest management. An examination of existing young stands in the region might be warranted.

Statistical treatment of the data was carried out to verify the significance of certain trends and differences and to permit assignment of confidence intervals to average values. Lack of curvilinearity was noted in certain of the data. Only second-degree parabolic curvilinearity was tested and it is possible that other mathematical formulae might verify curvilinear trends. It would seem equally possible that the specific regressions of percentage of decay and average net volume on age and diameter are in fact rectilinear.

It has been common practice, however, to demonstrate increasing decay and decreasing net volume at advanced ages and larger diameters, usually by free-hand graphical analysis. This practice has apparently developed from a concept of forest growth and mortality which recognizes that tree species live for a maximum period and may deteriorate with increasing rapidity during a period of decline. It may be necessary to consider that cyclic mortality depreciates most stands and consequently that percentage of decay and net volume fluctuates. Ingrowth could moderate such fluctuations as seen in even-aged stands of Douglas fir (4); this hypothesis may hold with equal validity in uneven-aged stands of tolerant species similar to those investigated in the present study. In such cases increasingly rapid deterioration need not necessarily follow with advanced age and yields would remain more or less constant. A lack of curvilinearity of data derived solely from mature forests would reflect this stability. Few trees of advanced age normally occur in mature forests and these generally are considered to be survivors which have withstood the ravages of time. In the present sample there were 64 fir trees in the 400-year-old class which averaged 31 per cent loss in volume and 6 trees over 550 years of age for which average loss reached 29 per cent. It is apparent that the mortality rate rises sharply between the two age classes and also that older surviving trees *per se* do not necessarily contain less sound wood than younger trees. Some sub-samples did in fact show higher loss with age but other samples indicated that net volume increased with age. In neither case, however, were the trends stable enough so that significant improvement could be gained through curvilinear regression.

ACKNOWLEDGMENTS

The authors are indebted to a number of persons for their co-operation in making available sample areas, equipment, and other facilities which contributed to the conduct of field investigations, but especially to the following: M. W. Gormely, formerly District Forester, British Columbia Forest Service, Prince

Rupert; H. Lynum, formerly Columbia Cellulose Company Limited, Terrace; and to J. E. Liersch, Executive Vice-President and formerly Chief Forester, and the late J. E. Tucker, Forester, Powell River Company, Vancouver.

We gratefully acknowledge the technical counsel of A. R. Fraser, Forester, British Columbia Forest Service, Victoria, and of C. Reimer, Statistical Research and Service Unit, Science Service, Ottawa. Dr. M. K. Nobles, Botany and Plant Pathology Division, Ottawa, provided an invaluable service by identifying cultures and various members of the Forest Biology Laboratory, Victoria, helped to compile the field data.

REFERENCES

1. Basham, J. T., P. V. Mook, and A. G. Davidson. New information concerning balsam fir decays in eastern North America. Can. J. Botany, 31: 334–360. (1953).
2. Bier, J. E., P. J. Salisbury, and V. J. Nordin. Studies in forest pathology. V. Decay in fir, *Abies lasiocarpa* and *A. amabilis*, in the Upper Fraser region of British Columbia. Can. Dept. Agr. Tech. Bull. 66. (1948).
3. Bier, J. E. Forest pathology in relation to the utilization and management of balsam and western hemlock in the Kitimat area, British Columbia. Can. Dept. Agr. Div. Botany and Plant Pathology. Mimeographed. (1945).
4. Boyce, J. S. and J. W. B. Wagg. Conk rot of old-growth Douglas fir in western Oregon. Oregon Forest Products Laboratory and Oregon State Forestry Dept. Bull. 4. (1953).
5. Browne, J. E. Decay of Engelmann spruce and balsam fir in the Bolean Lake area, B.C. Can. Dept. Agr. Forest Biology Div. Multigraphed. (1952).
6. Buckland, D. C., R. E. Foster, and V. J. Nordin. Studies in forest pathology. VII. Decay in western hemlock and fir in the Franklin River area, British Columbia. Can. J. Research, C, 27: 312–331. (1949).
7. Buckland, D. C., A. C. Molnar, and G. W. Wallis. Yellow laminated root rot of Douglas fir. Can. J. Botany, 32: 69–81. (1954).
8. Clarke, T. A. Report on cruise of the Kitimat Valley. Province of British Columbia, Forest Service. Typewritten Rept. (1921).
9. Clarke, T. A. Report on cruise of the Clearwater Valley. Province of British Columbia, Forest Service. Typewritten Rept. (1922).
10. Englerth, G. H. Decay of western hemlock in western Oregon and Washington. Yale University School of Forestry Bull. 50. (1942).
11. Farsted, F. and D. G. Laird. Soil survey of the Quesnel, Nechako, Francois Lake and Bulkley-Terrace areas in the central interior of British Columbia. Can. Dept. Agr., British Columbia Soil Survey Rept. No. 4. (1954).
12. Foster, R. E., G. P. Thomas, and J. E. Browne. A tree decadence classification for mature coniferous stands. For. Chron., 29: 359–366. (1953).
13. Foster, R. E. and A. T. Foster. Studies in forest pathology. VIII. Decay of western hemlock on the Queen Charlotte Islands, British Columbia. Can. J. Botany, 29: 479–521. (1951).
14. Foster, R. E., H. M. Craig, and G. W. Wallis. Studies in forest pathology. XII. Decay of western hemlock in the Upper Columbia region, British Columbia. Can. J. Botany, 32: 145–171. (1954).
15. Kimmey, J. W. Cull factors for Sitka spruce, western hemlock and western red cedar in southeast Alaska. U.S. Dept. Agr., Forest Service, Alaska Forest Research Centre Station Paper No. 8. (1956).
16. McCallum, A. W. Studies in forest pathology. I. Decay in balsam fir, (*Abies balsamea*, Mill.). Can. Dept. Agr. Bull. 104 (n.s.). (1928).
17. Mulholland, F. D. Report on examination of part of the Lakelse Valley, Coast Range 5. Province of British Columbia, Forest Service. Typewritten Rept. (1921).
18. Province of British Columbia. Climate of British Columbia. Rept. for 1955. (1956).

19. Tannhauser, J. R. Interim report on decay in the spruce-balsam type forests of the Prince George region. Can. Dept. Agr. Div. Botany and Plant Pathology. Typewritten Rept. (1950).

20. Thomas, G. P. and R. W. Thomas. Studies in forest pathology. XIV. Decay of Douglas fir in the coastal region of British Columbia. Can. J. Botany, 32: 630–653. (1954).

21. Thomas, G. P. Some aspects of the ecology of the Indian paint fungus, *Echinodontium tinctorium* Ell. & Ever. Can. Dept. Agr. Forest Biology Div. Multigraphed. (1955).

22. Thomas, G. P. A contribution to the further understanding of the occurrence of the Indian paint fungus, *Echinodontium tinctorium* E. & E. in British Columbia forests. Univ. of British Columbia, Dept. Biology and Botany. Typewritten Rept. (1956).

23. Weir, J. R. and E. E. Hubert. A study of heart-rot in western hemlock. U.S. Dept. Agr. Bull. 722. (1918).

24. Wright, E. and L. A. Isaac. Decay following logging injury to western hemlock, Sitka spruce, and true firs. U.S. Dept. Agr. Tech. Bull. 1148. (1956).